Current Biology Vol 15 No 16
R620

Correspondence

Chickens orient using a magnetic compass

Rafael Freire[1], Ursula H. Munro[2], Lesley J. Rogers[1], Roswitha Wiltschko[3] and Wolfgang Wiltschko[3]

Although behavioural experiments show that a wide range of animals use the earth's magnetic field as a compass for orientation, evidence from conditioning experiments has proved elusive [1]. In birds, the only two successful attempts of operant conditioning to magnetic stimuli [2,3] both involved magnetic anomalies rather than changes in magnetic direction. By using the young domestic chick's motivation to locate a hidden social stimulus [4], we have demonstrated the first conditioned magnetic compass response in birds and show that the ability to orient using magnetic cues has been retained after thousands of years of domestication [5].

Eight layer-strain domestic chicks were imprinted on a red table tennis ball and subsequently trained to locate this ball hidden behind one of four screens in the north, east, south or west corners of a square arena (Figure 1A). Each chick was released in the centre of the arena to search for the ball that had been hidden behind one of the screens. After finding the ball and remaining with it for one minute (reward), the chick was returned to the home pen while the arena was rotated. The chick was re-introduced after approximately 2–5 minutes into the arena for the next trial to locate its reward. Training continued until the chick approached the ball without deviation in three consecutive training trials (criterion). Unrewarded tests — no ball hidden behind screen — followed, in which we recorded the direction of the first screen that the chick walked behind.

Chicks received five tests in each of three conditions: first, the local geomagnetic field (control tests; 56000 nT, –62° inclination); second, an experimental magnetic field with magnetic North shifted by 90° clockwise to geographic East (shifted-north tests); and third, a field with the vertical component inverted, resulting in an inclination of +62° (inclination tests). These tests were presented in a random order and separated by one successful training trial. Training and the 15 tests took 2–4 days for each chick; the chicks were subjected to this procedure twice, at 10–14 and again at 19–23 days post-hatching (hence age was a within-subject factor in the analysis). Chicks reached criterion in 10–22 training trials and required on average 2.0 ± 0.18 training trials between tests during the first testing period, and reached criterion in 5–11 training trials and required on average 1.7 ± 0.16 training trials between tests during the second testing period.

The behaviour of the chicks was axial (Table 1), that is, they preferred the correct screen and the opposite screen in the control tests, as well as in the two experimental fields (Figure 1B). In control tests, 76 ± 3.7% (chance = 50%; $t = 7.5$, $P < 0.0001$) of their choices lay along this axis. In the shifted-north tests, 78 ± 3.1% of their choices lay on an axis shifted by 90° ($F_{1,6} = 49.4$, $P < 0.001$). This response to the shift in magnetic north was independent of the age of the chicks ($F_{1,6} = 0.21$, $P = 0.66$) and their sex ($F_{1,6} = 1.1$, $P = 0.34$). In the inclination tests, the choices were as in the control tests, with 79 ± 2.3% of the choices on the same axis ($F_{1,6} = 0.2$, $P = 0.67$). The chicks were not orienting using other non-magnetic cues from inside or outside the arena (see supplemental data); their orientation clearly depended on the direction of the ambient magnetic field.

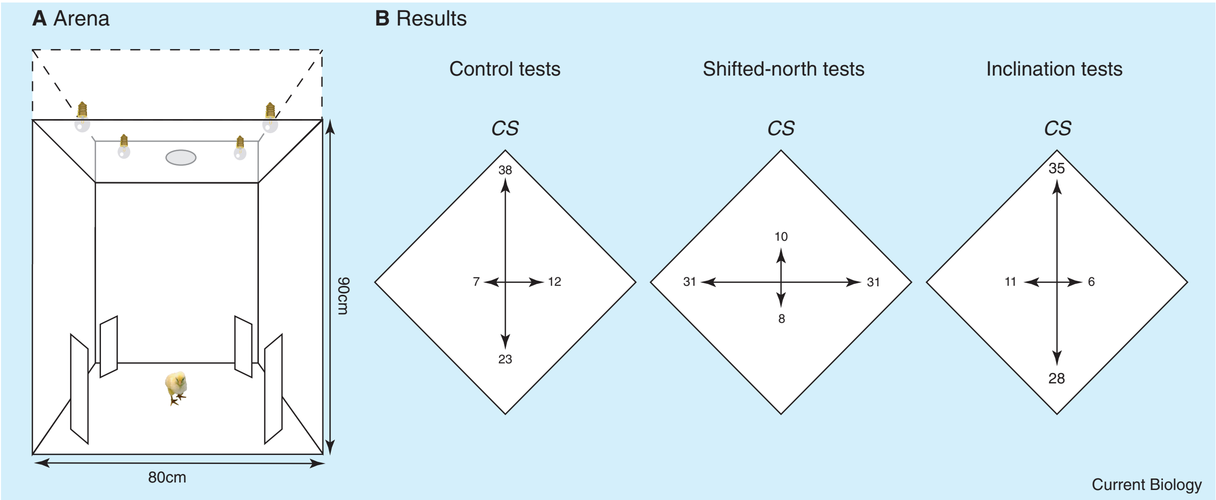

Figure 1. Experimental set up and the choices of the chicks.
(A) The arena used to train and test the chicks (for details, see supplemental data); the hole in the centre of the ceiling was for placing the camera lens. Before release, the chick was restrained in a clear plastic start cage in the center for 20 s in both training trials and tests. (B) The number of choices of each screen in the three test conditions; CS, correct screen in training trials.

Table 1. Sex, training direction and choices.

		Tests at 10–14 days post-hatching			Tests at 19–23 days post-hatching		
Chick	Trained to	Control	Shifted-north	Inclination	Control	Shifted-north	Inclination
1 F	N	NNeNw	WnWWW	SSSNN	NNwNN	sWWWW	wwNSS
2 M	N	NNwNS	EEEEE	NNNeS	SNNeS	WEEnE	wNNNN
3 F	E	EWnEs	SwNNe	nWEWW	sWEsW	NeNNN	EEWWW
4 M	E	EEEEW	wNSSS	EsWEE	sEEEE	NNNSS	WnEsE
5 F	S	NwNSS	WWnWW	wwSSS	SSeSN	sWsWW	NSSSS
6 M	S	wSwwN	EsEEW	SeSSS	NwSSN	WWEsW	eSSNS
7 F	W	WEWEW	weSSN	nEWEE	EEWsW	SwSSN	sEEWE
8 M	W	EEEWn	SeNeS	sEEsE	EsEWW	NeNNS	EEEWs

The table shows for each chick the sex (M, male; F, female), training direction — N, n, north; E, e, east; S, s, south; W, w, west — and the choices in five tests each in the three experimental conditions presented to individual chicks at two different ages; the choices along the correct axis are indicated by capital letters and the choices along the incorrect axis in small letters.

The axial response of our chicks contrasts with that of the other birds tested for magnetic compass orientation: migratory passerines as well as homing pigeons normally show unimodal magnetic responses [1]. The magnetic compass of these avian species is an inclination compass [1], based on the axial course of the field lines instead of their polarity [6]; the birds interpret the inclination of the field lines to obtain unequivocal information on magnetic directions. Our chicks, however, did not distinguish between the correct and the opposite direction, thus making it impossibly to decide whether or not their compass mechanism is also an inclination compass.

The axial response *per se* seems to suggest a primarily axial mechanism like the inclination compass [6] rather than a mechanism responding to magnetic polarity. Not distinguishing between the correct and the opposite direction may be indicative of the difficulty in orienting in the artificial test arena, or it may reflect a transient stage in the development of the orientation system. It seems possible that the mechanism allowing birds to distinguish the two ends of the magnetic field lines require a certain time to mature. To the young chick, additional orientation cues like landmarks [7] would be available to help overcome initial problems in orientation. As the development of brain function in chickens is well known, our finding may assist the neurobiological analysis of the avian magnetic compass.

The two previous successful studies [2,3] had used strong anomalies as stimuli, so that it remained unclear which magnetic parameter — change in intensity, local gradients or local changes in direction — caused the conditioned response. By using a social reward rather than a food reward, we could induce a strong directional tendency and thus demonstrate the first conditioned magnetic compass response in an avian species. Domestic chickens belong to an ancient lineage of birds, separated from the more modern birds already in the createaceous period [8]; their having a magnetic compass is of interest also from the phylogenetic point of view, in particular as they are largely ground-living, normally not covering larger distances. At the same time, the persistence of this mechanism after thousands of years of domestication [5] is remarkable and emphasised the important role of magnetic compass orientation even in non-migratory species.

Acknowledgments
We thank Craig Lawlor for assistance with the figure. Supported by the Deutsche Forschungsgemeinschaft (W.W.), the Human Frontier Sciences Program (R.W.) and a University of New England VC post-doctoral fellowship (R.F.).

Supplemental data
Supplemental data including experimental procedures are available at http://www.current-biology.com/cgi/content/full/15/16/R620/DC1/

References
1. Wiltschko, R., and Wiltschko, W. (1995). Magnetic Orientation in Animals. (Berlin: Springer).
2. Bookman, M.A. (1977). Sensitivity of the homing pigeon to an Earth-strength magnetic field. Nature *267*, 340–342.
3. Mora, C.V., Davison, M., Wild, J.M., and Walker, M.M. (2004). Magnetoreception and its trigeminal mediation in the homing pigeon. Nature *432*, 508–511.
4. Vallortigara, G., Regolin, L., Rigoni, M., and Zanforlin, M. (1998). Delayed search for a concealed imprinted object in the domestic chick. Anim. Cogn. *1*, 17–24.
5. Fumihito, A., Miyake, T., Takada, M., Shingu, R., Endo, T., Gojobori, T., Knodo, N., and Ohno, S. (1996). Monophylectic origin and unique dispersal patterns of domestic fowls. Proc. Natl. Acad. Sci. USA *93*, 6792–6795.
6. Wiltschko, W., and Wiltschko, R. (1972). Magnetic compass of European robins. Science *176*, 62–64.
7. Regolin, L., Garzotto, B., Rugani, P., and Vallortigara, G. (2005). Working memory in the chick: parallel and lateralized mechanisms for encoding object- and position-specific information. Behav. Brain Res. *157*, 1–9.
8. Cooper, A., and Penny, D. (1997). Mass survival of birds across the Cretaceous-Tertiary boundary: Molecular evidence. Science *275*, 1109–1113.

[1]Centre for Neuroscience and Animal Behaviour, University of New England, Armidale, NSW, Australia. [2]Department of Environmental Sciences, University of Technology, Sydney, Australia. [3]Zoologisches Institut der J.W.Goethe-Universität, Frankfurt Main, Germany.
*E-mail: rfreire2@une.edu.au